VERTICAL MOTION AT 100 MB. IN THE TROPICS

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ABSTRACT

Vertical motion at 100 mb. has been computed by the adiabatic method at each of 88 locations on a grid covering the Caribbean and adjoining areas and for each twice-daily map time during the periods, Jan. 3 to 5 and Aug. 3 to 5, 1963. The order of magnitude of vertical velocities in both winter and summer was the same, average values being about 4 mm./sec. in winter and 2 mm./sec. in summer. Local temperature change and temperature advection averaged about 2°C./day and 3°C./day respectively in winter, and both were about 1°C./day in summer. The correlation of vertical motion and temperature advection was high, about −0.86. These and other results are illustrated by maps showing the wind-isotherm patterns and the distribution of vertical motion at 100 mb. for six selected map times.

1. INTRODUCTION

Vertical velocities at stratospheric levels have been computed by several investigators (e.g., Kochanski [4], Epstein [2], Craig and Lateef [1]). Large-scale vertical motions in the upper stratosphere over North America were estimated by Kays and Craig [3] to be an order of magnitude larger in winter than in summer. All these investigations were largely confined to areas outside the Tropics. The purpose of this paper is to report on the results of vertical motion computations based on the adiabatic method, at 100 mb. over the Caribbean and adjoining areas for two selected periods, one in winter and the other in summer. The assumption of adiabatic temperature changes in the stratosphere have been justified by Craig and Lateef [1].

2. ANALYSIS AND COMPUTATIONAL PROCEDURES

Wind and temperature data have been analyzed for the region shown in figure 1, which also shows the grid used for the computations. The base map for all analyses was a mercator projection true to scale at 22.5°N. The grid consisted of a rectangular array of 130 points with a uniform grid interval of 2° long. The basic input data consisted of the appropriate distances for the grid and the wind direction, wind speed, and temperature at 100 mb. at each of the grid points and at twice-daily map times (00 and 12 GMT) during the periods Jan. 3 to 5 and Aug. 3 to 5, 1963. In connection with a previous investigation of vertical motion, divergence, and vorticity in the troposhpere over the Caribbean, wind and temperature data at 100 mb. for the period Aug. 3 to 5, 1963, were already available. No particular significance is implied in the selection, for comparison purposes, of a winter period of similar duration in the same year.

Wind direction and speed at each grid point were read from streamline-isotach analyses performed in the conventional manner. Twice-daily temperatures at 100 mb reported by the observing stations were first smoothed over time by the application of an elementary binomial smoothing function with weights ¼, ½, ¼, in order to minimize fluctuations due to any spurious diurnal variations and random errors. Isotherms were then drawn in a subjective manner such that they presented reasonably smooth patterns. Grid point values of temperature were interpolated from isotherms drawn at 1°C. intervals.

Vertical motion ω ($=dp/dt$, in the x, y, p, t coordinate system) has been computed from the relationship

$$\omega=\frac{\partial T/\partial t+\mathbf{v}\cdot\nabla_p T}{\kappa T/p} \tag{1}$$

where T is temperature, p is pressure ($=100$ mb.), $\mathbf{v}$ is

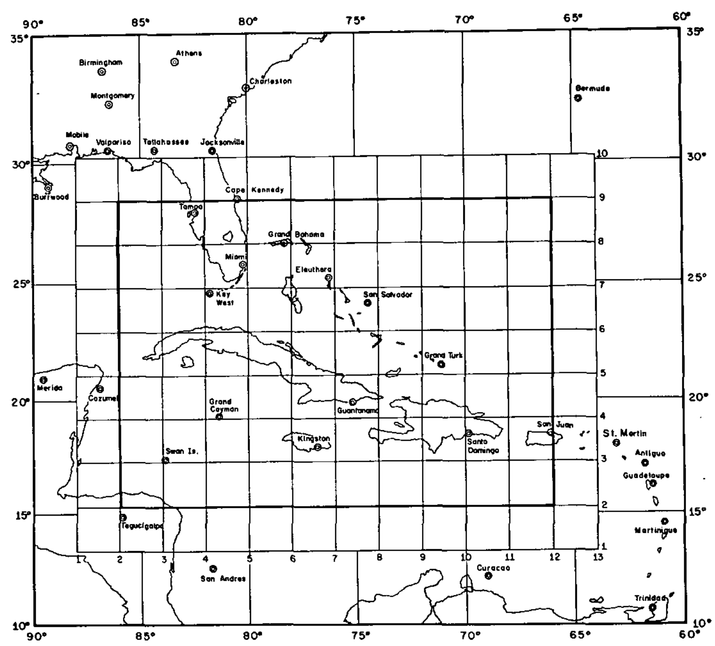

FIGURE 1.—Base map used for analyses and grid over which computations were made. The perimeter of the grid over which vertical velocities were calculated is shown in heavy lines.

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the horizontal component of the wind, ∇_p is gradient along the constant pressure surface and κ is the ratio of the gas constant to specific heat at constant pressure of dry air. The vertical velocity w is obtained from ω through the relationship

$$w=-\left(\frac{RT}{gp}\right)\omega \tag{2}$$

where R is the gas constant for dry air.

The finite difference approximations used for the computation of terms in the numerator of (1) are as follows:

$$(\partial T/\partial t)_{t_0}=\frac{1}{24\text{ hr.}}\left[T_{(t_0+12\text{ hr.})}-T_{(t_0-12\text{ hr.})}\right] \tag{3}$$

$$\mathbf{v}\cdot\nabla_p T=\frac{u_{(i,j)}[T_{(i+1,j)}-T_{(i-1,j)}]+v_{(i,j)}[T_{(i,j+1)}-T_{(i,j-1)}]}{2d_{(i,j)}} \tag{4}$$

$$(\mathbf{v}\cdot\nabla_p T)_{t_0}=0.25(\mathbf{v}\cdot\nabla_p T)_{t_0-12\text{ hr.}}+0.50(\mathbf{v}\cdot\nabla_p T)_{t_0}+0.25(\mathbf{v}\cdot\nabla_p T)_{t_0+12\text{ hr.}} \tag{5}$$

Here t_0 refers to a specific map time, i and j are grid point numbers along latitude and longitude respectively, and $d\ (i, j)$ is the grid distance. Values of ω are available only at the 88 points of the inner grid (fig. 1) because of finite difference approximations to horizontal derivatives.

In view of the observed slow changes in the wind and temperature fields at stratospheric levels, the 24-hr. centered difference used for computing $\partial T/\partial t$ term usually yields the correct sign and approximate magnitude of the time change of temperature over a shorter period centered at map time. The 24-hr. integration scheme (5), for computing the temperature advection term is an attempt, however, to reconcile the time scale used in (3) with the space scale involved in (4). The computed vertical velocities may, therefore, be considered as averages over a 24-hr. period centered at map time.

Uncertainties in the computed magnitudes of the temperature advection term are inevitable especially in view of the observed fact that isotherms often tend to parallel the winds. Based on estimates of errors in the computation of this term, allowing reasonable combinations of wind direction or speed and orientation of isotherms, it is believed that the computed magnitudes of the advection term are not likely to be incorrect by more than 30 percent.

The magnitude of the term, $\kappa T/p$, in the denominator of (1) can be determined to within a few percent of the true value and averages about 0.58°C./mb. at 100 mb. over the analysis area in both winter and summer. In the complete formulation of adiabatic temperature changes, the denominator of (1) would contain the additional term, $-\partial T/\partial p$. It is observed that in summer at 100 mb. this term is invariably very small, about 0.03°C./mb., and its omission does not affect appreciably the computed values of ω. Examination of temperature profiles near 100 mb. at the observing stations during the winter period indicates that whenever $\partial T/\partial p$ is negative (temperature increasing with height) its value seldom exceeds 0.15°C./mb. The corresponding increase in the magnitude of the denominator $(\kappa T/p)-(\partial T/\partial p)$, would lead to about 25 percent reduction in the ω-values. When $\partial T/\partial p$ is positive, its value occasionally reaches about 0.30°C./mb., resulting in about 50 percent error in the computed values of ω. In any case, the omission of the $\partial T/\partial p$ term in the denominator of (1) will not affect the sign or order of magnitude of the computed vertical velocities.

TABLE 1.—*RMS values of time change of temperature, temperature advection, and vertical velocity at 100 mb.*

Map time		$\partial T/\partial t$ (°C./day)	$\mathbf{v}\cdot\nabla_p T$ (°C./day)	$\kappa T/p$ (°C./mb.)	w (mm./sec.)
GMT	1963	Winter			
0000	Jan. 3	1.0	4.3	0.59	5.0
1200	Jan. 3	1.7	3.4	0.58	2.0
0000	Jan. 4	2.2	2.6	0.58	2.2
1200	Jan. 4	2.4	2.4	0.58	4.5
0000	Jan. 5	2.6	2.6	0.57	5.1
	Average....	1.9	3.1	0.58	3.8
		Summer			
0000	Aug. 3	0.7	1.2	0.58	1.6
1200	Aug. 3	1.4	1.4	0.58	2.9
0000	Aug. 4	1.7	1.2	0.58	2.4
1200	Aug. 4	1.4	1.2	0.58	2.5
0000	Aug. 5	1.0	1.4	0.57	1.9
	Average....	1.2	1.2	0.58	2.3

3. RESULTS OF COMPUTATIONS

Table 1 gives the root-mean square values at 100 mb. of the time change term, the advection term, the $\kappa T/p$ term, and vertical velocity over the analysis area at each map time for the two selected winter and summer periods. Though the samples are not large enough, the following tentative conclusions can be deduced in respect of the overall behavior of these terms on a scale appropriate to the grid distance used: 1) The time change term and the temperature advection term are of the same order of magnitude. 2) The temperature advection term during winter is about two to three times its magnitude during summer. 3) There is no appreciable seasonal variation in the values of the $\kappa T/p$ term, when averaged over the area. 4) Vertical velocities in winter tend to be slightly larger in magnitude than values in summer.

Previous investigations, confined largely to areas north of the Tropics, have established that, at least in winter, the sign and magnitude of vertical motion at stratospheric levels is determined by the temperature advection term, because the time change of temperature is relatively small [1, 2, 3]. One would not, *a priori*, expect the same to be true for the area under study, since, as mentioned earlier, the local change of temperature is of the same order of magnitude as that of the advection term. Table 2 gives the correlation coefficient between grid point

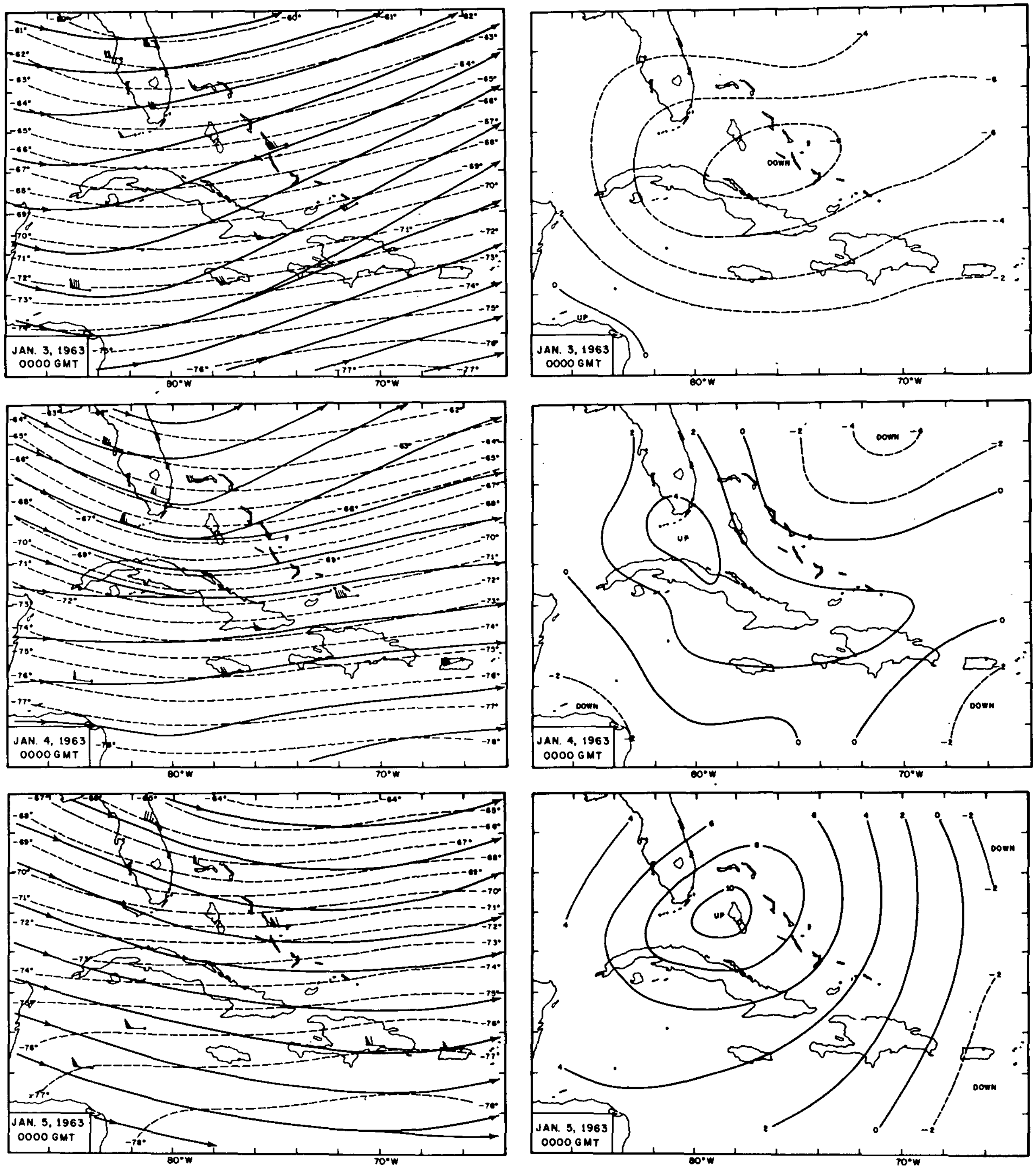

FIGURE 2.—Streamlines and isotherms (left) and vertical motion (right) at 100 mb. at 00 GMT, Jan. 3 to 5, 1963. Wind speeds are indicated in m./sec. (long barb represents 10 m./sec. and short barb 5 m./sec.). Isotherms are shown by dashed lines and labeled in °C. Isopleths of vertical motion are labeled in mm./sec.

TABLE 2.—*Correlation coefficients between vertical velocities and time change and advection terms at 100 mb.*

Map time		Correlation coefficients between w and	
GMT	1963	Time change of temperature	Temperature advection
0000	Jan. 3	−0.74	−0.96
1200	Jan. 3	−0.64	−0.86
0000	Jan. 4	−0.42	−0.88
1200	Jan. 4	−0.62	−0.91
0000	Jan. 5	−0.61	−0.89
0000	Aug. 3	−0.61	−0.87
1200	Aug. 3	−0.59	−0.79
0000	Aug. 4	−0.27	−0.89
1200	Aug. 4	−0.49	−0.74
0000	Aug. 5	−0.49	−0.85
	Average	−0.55	−0.86

value of vertical velocity and both the time change and the advection term. The interesting feature of these results is the high correlation between vertical velocity and the temperature advection term at 100 mb., in spite of the appreciable contribution of the time change term to the vertical velocity value. The average correlation of −0.55 between vertical velocity and 24-hr. temperature change is, however, at variance with the value of −0.03 for a similar correlation obtained by Miller [5]. Adopting a single station technique to compute adiabatic vertical velocities during selected time intervals in winter, at various levels including 100 mb. over San Juan, Puerto Rico, Miller found that the correlation between vertical

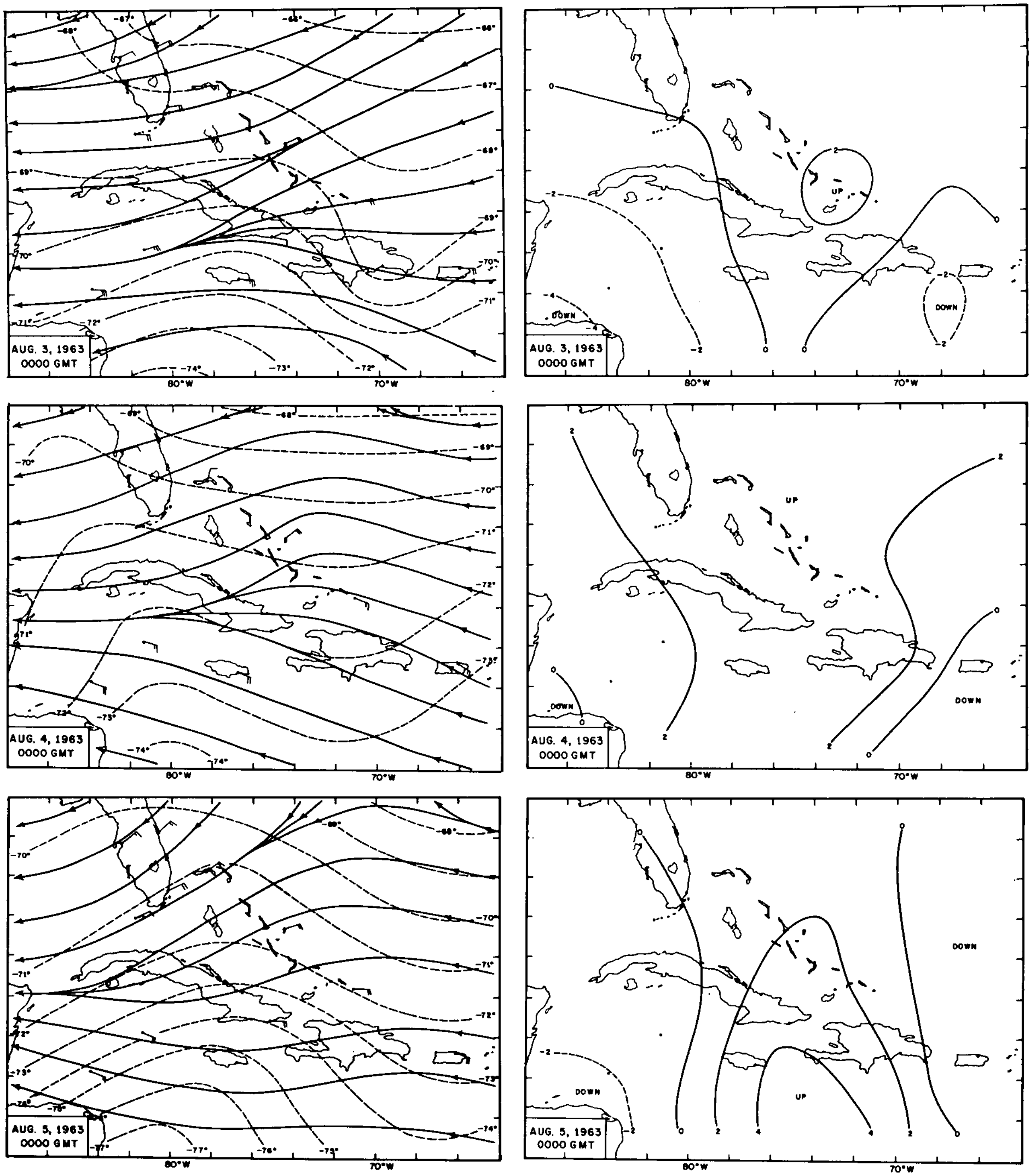

FIGURE 3.—Streamlines and isotherms (left) and vertical motion (right) at 100 mb. at 00 GMT, Aug. 3 to 5, 1963. Wind speeds are indicated in m./sec. (long barb represents 10 m./sec. and short barb 5 m./sec.). Isotherms are shown by dashed lines and labeled in °C. Isopleths of vertical motion are labeled in mm./sec.

velocity and temperature advection, as computed from the vertical wind shear (see Panofsky [6]) was −0.96, in conformity with the average correlation of −0.86 between vertical velocity and temperature advection computed in the present study.

Correlation coefficients between the 24-hr. temperature changes and the temperature advection terms, computed for the 10 map times, are uniformly low and range in values from −0.20 to 0.23. Apparently the variations in the values of local temperature changes are such that, in the region under study, they do not affect the dominant role of temperature advection in determining the sign and intensity of vertical motion at 100 mb.

The wind-isotherm patterns as well as the distribution of vertical velocities at six selected map times are shown in figures 2 and 3. No particular relationship exists between the signs of vertical motion and the positions of weak troughs and ridges in the easterly flow at 100 mb. in summer. In the winter sample, relatively intense descent is observed some distance downwind (east) of the trough in at least one instance and relatively pronounced ascent is noticed upwind (west) of the trough.

4. SUMMARY

In this paper, computations of vertical motion at 100 mb. over the Caribbean and adjoining areas during two particular periods, January 3 to 5 and August 3 to 5, 1963, have been described. The results are not necessarily applicable to other areas in the Tropics or other time periods. A summary of the results of the computations is given below, so that they may be compared with those of other similar studies:

1) Local temperature change and temperature advection were comparable in magnitude in summer and were, on the average, about 1°C./day. Both these quantities were larger in magnitude during winter, local temperature change being about 2°C./day and temperature advection about 3°C./day.

2) The average magnitude of vertical velocities was about 4 mm./sec. in winter and about 2 mm./sec. in summer. Extreme magnitudes of vertical motion were about 10 mm./sec. in winter and 5 mm./sec. in summer.

3) In spite of the relative importance of the time change of temperature, horizontal temperature advection was the dominant factor in determining the sign and intensity of vertical motion at 100 mb.

ACKNOWLEDGMENTS

The author is thankful to Mr. H. F. Hawkins, Dr. S. L. Rosenthal, and Dr. B. I. Miller of the National Hurricane Research Laboratory for their helpful criticisms.

REFERENCES

1. R. A. Craig and M. A. Lateef, "Vertical Motion During the 1957 Stratospheric Warming," *Journal of Geophysical Research*, vol. 67, No. 5, May 1962, pp. 1839–1854.
2. E. S. Epstein, "Large-Scale Vertical Motion in the Stratosphere," *Final Report*, Part 2, Contract AF19(604)–2190, Pennsylvania State University, University Park, Dec. 1959, 122 pp.
3. M. Kays and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *Journal of Geophysical Research*, vol. 70, No. 18, Sept. 1965, pp. 4453–4461.
4. A. Kochanski, "Thermal Structure and Vertical Motion in the Lower Stratosphere," *Technical Report* 105-129, Air Weather Service, Washington, D.C., Dec. 1954, 36 pp.
5. B. I. Miller, "High Level Vertical Motion in Relation to Tropical Rainfall," *Monthly Weather Review*, vol. 81, No. 10, Oct. 1953, pp. 319–325.
6. H. A. Panofsky, "The Effect of Vertical Motion on Local Temperature and Pressure Tendencies," *Bulletin of the American Meteorological Society*, vol. 25, No. 7, Sept. 1944, pp. 271–275.

[*Received September 21, 1967; revised November 8, 1967*]